New ecological model uses tournament-style framework of biodiversity

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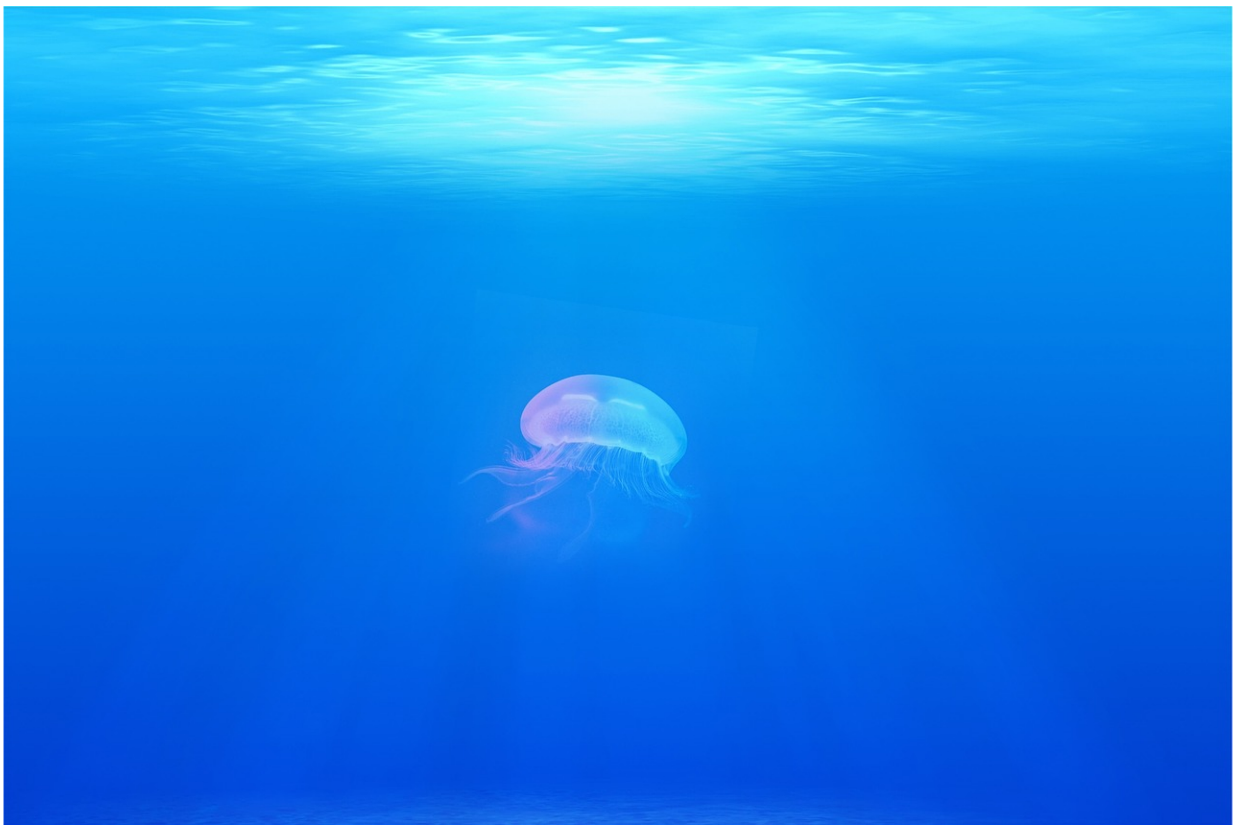

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A new mathematical model of ecology created by University of Chicago scientists provides the most accurate reproduction to date of natural biodiversity, according to a new paper in the journal *Nature*.

For almost a century, ecologists have conceptualized an ecosystem as the sum of pairwise interactions, such as predator and prey, herbivore and plant, or parasite and host. However, equations based on that theory failed to replicate the diversity and resilience of natural ecosystems.

Building upon previous work that modeled competition between species as similar to a game of "Rock Paper Scissors," a team led by Stefano Allesina, professor of ecology and evolution and a member of the Computation Institute at the University of Chicago, found that adding additional competitors could generate stable and robust model ecosystems.

"Ecologists feel more comfortable with pairs, but that doesn't mean that nature operates in pairs," said Allesina. "No one had proposed equations for triplets or quadruplets. We wanted to test if these relationships really make a difference, and the answer is a resounding yes; They make a huge difference."

Ecologists have long debated the existence and importance of higher-order interactions, where the relationship of two species can be influenced by a third. For example, the trio of a carnivore, a herbivore and a plant would be treated as independent carnivore-herbivore and herbivore-plant pairs. But the presence of a carnivore could force the herbivore into hiding, affecting its consumption of the plant—a higher-order interaction that disrupts the pairwise model.

"If you measure these pairs and put them together, they don't explain the system," Allesina said. "Basically the presence of the predator modifies the relationship between the plant and the herbivore. Something emerges that cannot be explained by pairs."

In the Nature paper, Allesina, postdoctoral researchers Jacopo Grilli and György Barabás, and graduate student Matthew Michalska-Smith considered a simple scenario: In a hypothetical forest where every so often one tree dies and leaves a hole in the canopy, who will win a battle of species to fill that ecological gap?

If a pair of species compete for each opening, the dominant competitor will eventually drive the other extinct and lower ecosystem diversity, unless they are perfectly equal. In the "Rock Paper Scissors" model proposed by Allesina's group in 2011, overlapping dominance (e.g. rock beats scissors but loses to paper) of multiple species can maintain a rich ecosystem, but the biodiversity cycles between high and low in a pattern not observed in nature.

To instead model the system with higher-order interactions, the team simulated competition using a "stepladder tournament" format similar to that used in televised bowling events. Here, the winner of a two-way match goes on to play against a third competitor, and the winner of that match plays a fourth, and so on, for any number of competitors. With an equation that aggregates all possible outcomes of one of these "chain of competitions," the researchers found they could produce a system with high and stable biodiversity, similar to observations from the real world.

Unlike other ecological models, their equation produced realistic results under a wide range of starting conditions, as well as in both a closed system—akin to bacteria competing in a laboratory dish—and an open system, where new species enter and leave the ecosystem over time.

"When there is even the probability of just three species interacting, it completely changes the dynamics," Grilli said. "As long as there is a very small probability for higher-order interactions to happen, then there are going to be huge changes. It's really an effect that is super robust."

The researchers now hope to test their new equation in laboratory experiments, observing whether actual competition between bacterial species follows their model's predictions. In the meantime, by mathematically proving the strong influence of these higher-order interactions, Allesina expects the model to further push theoretical ecology into new territory.

"I think that this opens the door for a number of models that people had not considered before, that are maybe even simpler than this one," Allesina said. "It is very rare in ecology to see a model that has this kind of global stability, such that wherever you start you end up in the same point."

The new model also led Allesina's group back to familiar territory: The world of competitive "Rock Paper Scissors."

"If you apply this equation to come up with rules to play "Rock Paper Scissors" with three people, these turn out to be the official rules that they use," Grilli said. "In fact, we have a way to generalize for any number of players, so if you want to play the game with eight people, we can do that."

More information: Jacopo Grilli et al. Higher-order interactions stabilize dynamics in competitive network models, *Nature* (2017). DOI: 10.1038/nature23273

Provided by University of Chicago

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